

What is claimed is:

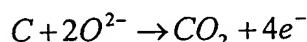
1. A direct-electrochemical-oxidation fuel cell for generating electrical energy from a solid-state organic fuel comprising:

5 a cathode provided with an electrochemical-reduction catalyst that promotes formation of oxygen ions from an oxygen-containing source at the cathode;

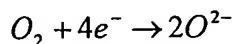
an anode provided with an electrochemical-oxidation catalyst that promotes direct electrochemical oxidation of the solid-state organic fuel in the presence of the oxygen ions to produce electrical energy; and

10 a solid-oxide electrolyte disposed to transmit the oxygen ions from the cathode to the anode, wherein

direct electrochemical oxidation at the anode occurs according to the reaction:



2. The fuel cell according to claim 1, wherein formation of the oxygen ions at the cathode 15 proceeds according to the reaction:



3. The fuel cell according to claim 1, wherein the solid-state organic fuel is coal, graphite, biomass or a combination thereof.

20

4. The fuel cell according to claim 3, wherein the biomass is selected from a group consisting of peat, rice hulls, and corn husks.

25 5. The fuel cell according to claim 1, wherein the direct electrochemical oxidation at said anode produces a product comprising a CO₂ concentration of at least 50 mol %.

6. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is lanthanum strontium manganese oxide.

5 7. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is selected from the group consisting of LSF; LSCF; SSC; $\text{YBa}_2\text{Cu}_3\text{O}_y$, wherein y is an integer having values within a range of 7-9; $\text{La}_{0.99}\text{MnO}_3$; LaMnO_3 ; $\text{La}_x\text{Sr}_y\text{Mn}_3$ and $\text{La}_x\text{Ca}_y\text{MnO}_3$, wherein x is a number having values within a range of 0.6-0.95, and y is a number having values within a range of 0.1-0.4.

10 8. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is selected from the group consisting of material having a general formula of $\text{A}_x\text{B}_y\text{CO}_3$, wherein A is selected from the group consisting of La, Gd, Sm, Nd, Pr, Tb and Sr, B is selected from the group consisting of Sr, Ce, and Co, x is a number having values within a range of 0.6-0.94, and y is a number having values within a range of 0.1-0.4.

15 9. The fuel cell according to claim 1, wherein the electrochemical-oxidation catalyst provided to the anode includes platinum.

20 10. The fuel cell according to claim 1, wherein the electrochemical-oxidation catalyst includes Rhenium.

11. The fuel cell according to claim 10, wherein the electrochemical-electrochemical oxidation catalyst is Re-NiO/YSZ.

12. The fuel cell according to claim 10, wherein the electrochemical-oxidation catalyst is Cu oxide-Pt.

13. The fuel cell according to claim 1, wherein the solid-oxide electrolyte is selected from the group consisting of doped oxides of Bi, Zr, Hf, Th, and Ce with either alkaline earth oxides such as CaO or MgO, or rare-earth oxides such as Sc_2O_3 , Y_2O_3 , Yb_2O_3 , and the like. For example, embodiments of the present invention include a solid-oxide electrolyte 18 comprising at least one of Bi_2O_2 , $(\text{Bi}_2\text{O}_7)_{0.75}(\text{Y}_2\text{O}_3)_{0.25}$, $\text{BaTh}_{0.9}\text{Gd}_{0.1}\text{O}_3$, $\text{La}_{0.8}\text{Sr}_{0.2}\text{Ga}_{0.8}\text{Mg}_{0.2}\text{O}_3$, $(\text{Ce}_2)_{0.8}(\text{GdO}_{0.5})_{0.2}$, $(\text{ZrO}_2)_{0.9}(\text{Sc}_2\text{O}_3)_{0.1}$, $(\text{ZrO}_2)_{0.9}(\text{Y}_2\text{O}_3)_{0.1}$, $(\text{ZrO}_2)_{0.87}(\text{CaO})_{0.13}$, $(\text{La}_2\text{O}_3)_{0.95}(\text{SrO})_{0.05}$.

14. The fuel cell according to claim 1, wherein the solid-oxide electrolyte is selected from the group consisting of yttrium-stabilized zirconium and bismuth oxide.

15. 15. The fuel cell according to claim 1 further comprising a housing that encloses the anode for receiving the solid-state organic fuel.

16. The fuel cell according to claim 15 further comprising feed passage through which the solid-state organic fuel can be inserted into the housing.

20

17. The fuel cell according to claim 1, wherein the electrochemical oxidation that occurs at the anode produces a product comprising a NO_x concentration of less than 5 mol %, wherein x is an integer within a range of 1 to 3.

25 18. The fuel cell according to claim 17, wherein the fuel cell has a maximum operating temperature of about 1200°C.

19. The fuel cell according to claim 1, wherein the direct electrochemical oxidation that occurs at the cathode results in a product comprising a CO concentration that is less than 10 mol %.

5

20. The fuel cell according to claim 19, wherein the fuel cell has a maximum operating temperature of about 1200°C.

21. The fuel cell according to claim 1, wherein the fuel cell produces an electrical current of
10 at least 100 mA/cm² for a period of time lasting at least 48 hours.

22. The fuel cell according to claim 1, wherein the fuel-conversion efficiency of the fuel cell is at least 30 mol % at 950°C.

15 23. A direct-electrochemical-electrochemical oxidation fuel cell for generating electrical energy from a solid-state organic fuel comprising:

a cathode provided with an electrochemical-reduction catalyst that promotes the formation of ions from an ion source at the cathode;

20 a anode provided with an electrochemical-oxidation catalyst that includes a sulfur-resistant material and promotes electrochemical oxidation of the solid-state organic fuel in the presence of the ions formed at the cathode to produce electrical energy; and

a solid-oxide electrolyte disposed to transmit the ions from the cathode to the anode.

24. The fuel cell according to claim 23, wherein the sulfur-resistant material includes at least
25 one of Re, Mn and Mo.

25. The fuel cell according to claim 24, wherein the sulfur-resistant material is selected from the group consisting of Re-NiO/YSZ, Cu oxide-Pt.

5 26. The fuel cell according to claim 23, wherein the electrochemical-reduction catalyst is lanthanum strontium manganese oxide.

10 27. The fuel cell according to claim 23, wherein the electrochemical-reduction catalyst is selected from the group consisting of LSF; LSCF; SSC; $\text{YBa}_2\text{Cu}_3\text{O}_y$, wherein y is an integer having values within a range of 7-9; $\text{La}_{0.99}\text{MnO}_3$; LaMnO_3 ; $\text{La}_x\text{Sr}_y\text{Mn}_3$ and $\text{La}_x\text{Ca}_y\text{MnO}_3$, wherein x is a number having values within a range of 0.6-0.95, and y is a number having values within a range of 0.1-0.4.

15 28. The fuel cell according to claim 23, wherein the ions formed at the cathode are oxygen ions formed according to the reaction:

$$\text{O}_2 + 4e^- \rightarrow 2\text{O}^{2-}$$

20 29. The fuel cell according to claim 23, wherein the solid-state organic fuel is coal, graphite, biomass, polymers or a combination thereof.

30. The fuel cell according to claim 29, wherein the biomass is selected from a group consisting of peat, rice hulls, and corn husks.

31. The fuel cell according to claim 23, wherein the solid-oxide electrolyte is selected from the group consisting of doped oxides of Bi, Zr, Hf, Th, and Ce with either alkaline earth oxides such as CaO or MgO, or rare-earth oxides such as Sc₂O₃, Y₂O₃, Yb₂O₃, and the like. For example, embodiments of the present invention include a solid-oxide electrolyte 18 comprising at

5 least one of Bi₂O₂, (Bi₂O₇)_{0.75}(Y₂O₃)_{0.25}, BaTh_{0.9}Gd_{0.1}O₃, La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O₃, (Ce₂)_{0.8}(GdO_{0.5})_{0.2}, (ZrO₂)_{0.9}(Sc₂O₃)_{0.1}, (ZrO₂)_{0.9}(Y₂O₃)_{0.1}, (ZrO₂)_{0.87}(CaO)_{0.13},

(La₂O₃)_{0.95}(SrO)_{0.05}.

32. The fuel cell according to claim 31, wherein the solid-oxide electrolyte is selected from
10 the group consisting of yttrium-stabilized zirconium and bismuth oxide.

33. The fuel cell according to claim 23, wherein electrochemical oxidation of the solid-state organic fuel at the anode produces a product having a CO₂ concentration of at least 50 mol %.

15 34. The fuel cell according to claim 33, wherein the fuel cell has a maximum operating temperature that is less than 1200°C.

35. The fuel cell according to claim 23, wherein electrochemical oxidation of the solid-state organic fuel at the anode produces a product having a NO_x concentration that is less than 0.1 mol
20 %, wherein x represents integers ranging from 1 to 3.

36. The fuel cell according to claim 23, wherein the electrochemical-oxidation catalyst is selected from the group consisting of a noble metal, group VIII metal/metal oxide, such as Pt, Cu, Ag, Au, Pd, Ni, oxides of the aforementioned sulfur-resistant materials, oxides of Ce, Cr, Fe,
25 and Pb, combinations thereof, multiple oxides, combinations including one or more of the aforementioned metals, Cu oxide-Pt, and Re-NiO/YSZ, wherein the electrochemical-oxidation

catalysts including non-noble metals also include a sulfur-resistant substance selected from the group consisting of Re, Mn, Mo, Ag, Cu, and Au.

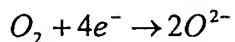
37. A method of generating electric power from a solid-state organic fuel, said method
5 comprising the steps of:

forming oxygen ions from an oxygen-containing source at a cathode;

transmitting the oxygen ions formed at the cathode to an anode with a solid-oxide electrolyte; and

10 catalyzing a reaction of the oxygen ions with the solid-state organic fuel to directly
oxidize the solid-state organic fuel at the anode to produce a product comprising CO₂ and
electrical energy.

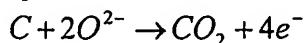
38. The fuel cell according to claim 37, wherein the step of forming oxygen ions comprises
the step catalyzing a reaction at the cathode with a lanthanum strontium manganese oxide
15 catalyst according to the formula:



39. The fuel cell according to claim 37, wherein the step of catalyzing the reaction of the
oxygen ions further comprises the steps of:

20 providing a catalyst comprising a sulfur-resistant material to the anode; and

directly electrochemically oxidizing the solid-state organic fuel according to the reaction:



40. A method of generating electric energy from a solid-state organic fuel, said method comprising the steps of:

establishing an ionic-communication channel between a cathode and an anode with a solid-oxide electrolyte

5 providing an electrochemical-oxidation catalyst that includes a sulfur-resistant material to the anode, wherein the electrochemical-oxidation catalyst promotes direct electrochemical oxidation of the solid-state organic fuel at the anode to produce a product comprising CO₂ and electrical energy;

10 providing an electrochemical-reduction catalyst to the cathode, wherein the electrochemical-reduction catalyst promotes the production of oxygen ions from an oxygen-containing source; and

forming a conductive channel to conduct the electrical energy away from the cathode.